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Pneumatic Valve Operated by Multiplex Pneumatic Transmission*

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Abstract

A pneumatic system has several advantages, which are cheapness, lightweight, and reliability to human and environment. These advantages are adapted to some research areas, such as industrial lines, medical and nursing cares, and rehabilitation tools. However, the pneumatic system needs several devices; compressor, air tube, and control valve. This research aim to downsize pneumatic system. In this paper, a new method of multiplex pneumatic transmission for multi-pneumatic servo system is proposed. The valve for this system consists of two vibrators supported by springs, which was designed with simple and cheap structure. The working principle of the valve is vibrators resonance from multiplex pneumatic transmission and it is possible to work as ON/OFF valves without electric wire. Dynamic simulation was used to confirm the working principle of the resonance driving system. A prototype device confirming the principle was designed and developed based on the simulation. The experiments show that this new control system works very well to control two separated valves through single pneumatic tube.

Key words: Actuator, Control Valve, Multiplex Pneumatic Transmission, Pneumatic System, Dynamic Simulation, Emission Valve, Resonance

1. Introduction

Pneumatic actuators have several advantages with its high compliance, lightweight, cheapness, and simple structure. These advantages are different from other actuators; electromagnetic actuators, piezoelectric actuators and thermal actuators. For example, electromagnetic actuators require large and heavy mechanism, while pneumatic actuator has advantage of simplexes, lightweight and high compliance.

Recently, development of systems and devices using this actuator is increased. Pneumatic actuators are essential for research in medical and human related areas because of its reliability to human and environment. It can provide further safety factor in all applications involving direct contact with people, such as in hospital environment. Therefore many researches have been medical areas and rehabilitation tools based on these advantages [(1) - (4)]. The force given from the pneumatic actuator which is softer differs from the other types of actuators making it effective in these applications. However, pneumatic actuator has its drawback where it requires larger system with air tube, control valve, and compressor. This make pneumatic actuator is not intended for portable systems and application. The realization of this research is to downsize this system.

Meanwhile, pneumatic actuator especially pneumatic cylinders are widely used in industries where portability is not needed. Factors of cheapness, lightweight, and reliability to environment are very concerned. However, control valve have constraint of electric wire

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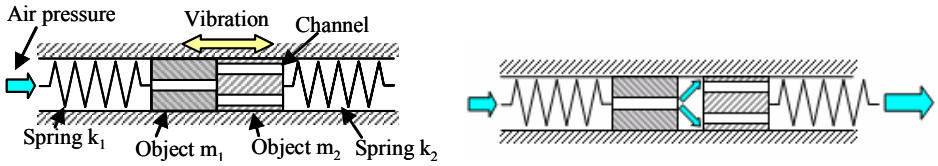
connected and the number wires are increasing proportionally to the numbers of pneumatic actuators. For example, robots with many degrees of freedom and mechatronics systems require more actuators and valves. Therefore this research is aim to ease this problem.

Downsizing of pneumatic actuators have been in done in previous research. For example, high portability compressors were developed [5] [6] and simple pneumatic valves were realized as piezoelectric actuator [7] [8]. However, these researches use valves with electric wires which are not intended to downsize the pneumatic system.

In this research, a new method of multiplex pneumatic transmission for multi-pneumatic servo system is proposed. The servo system is configured by a new principle of control valve through resonance drive of mass-spring system. This valve consisting of vibrators and springs can be driven without electric wires are cheap, simple and reliable to human and environment. In this paper, the results of simulation and experiments are reported to validate the working principle.

2. Principle of the proposed valve

Figure 1 shows the working principle of proposed valve. This valve is configured by vibrators and springs and is set to counterbrace. The vibrators are idle when pressure is supplied to each mass-spring system by sinusoidal waveform. The two vibrators will oscillate and contact each other when the sinusoidal wave frequency is non-resonance frequency as shown in Fig. a). However, during resonance frequency, the two vibrators will be in separate state as in Fig. b). In this separated state, air can flow through a channel in vibrators making it work as an ON/OFF valve without electric wire.



(a) Non-resonance frequency (b) Resonance frequency

Fig. 1 Principle of the proposed valve

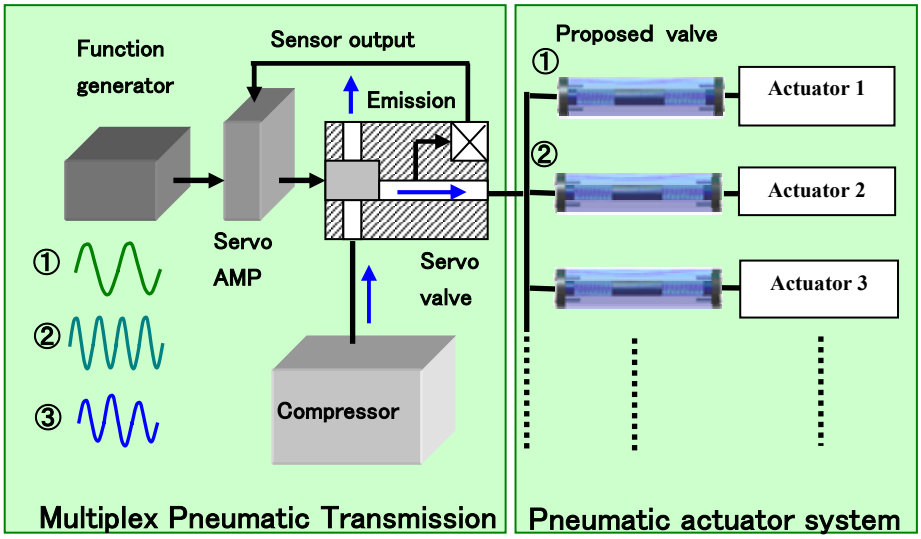


Fig. 2 Pneumatic system using proposed valve

This valve can ease the conventional pneumatic system. Figure 2 shows pneumatic system applying this valve for many degrees of freedom application. The signal for controlling the valve is sinusoidal waveform from the servo system. Input signal to the proposed valve corresponds to the numbered sinusoidal signal in Fig.2. The sinusoidal wave signals to drive each valve are superimposed into pneumatic supply line as air vibrator. In this research, the superimposed wave is called multiplex pneumatic transmission. This sinusoidal wave can drive each valve independently, making this system very effective for pneumatic system having many degrees of freedom.

3. Simulation

A dynamic simulation for proposed valve was performed. Figure 3 shows the simulation model which is configured by two mass-spring systems. A pressure substituted for a force was calculated from cross section of vibrator and pneumatic pressure. The force function is in sinusoidal wave as shown in Eq. (1). A is the amplifier parameter which assume real pressure and cross section of vibrator and f represents the frequency of sinusoidal wave which switches resonant/non-resonant vibrator of the valve, while P_o is the offset value of the function. The simulation shows that force from the springs result in clearance between two vibrators during the resonance frequency while they result in no clearance for non-resonance frequency. The hold force is determined by default amount of compression. Figure 4 below shows an example of simulation results. Each line shows the position of each vibrator in resonance frequency and non resonance frequency.

$$F = A \times \sin(2 \times \pi \times f) + P_o \qquad (1)$$

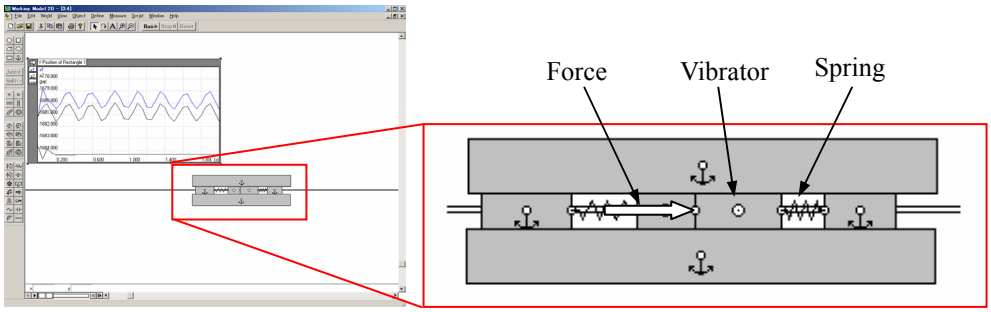


Fig. 3 Simulation model

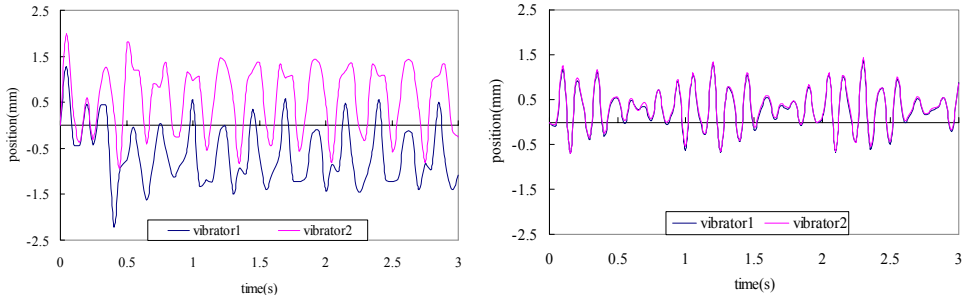
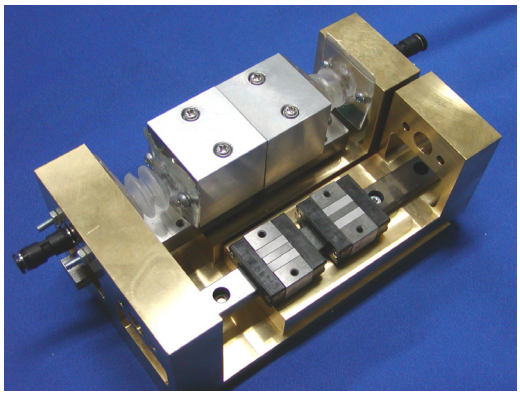


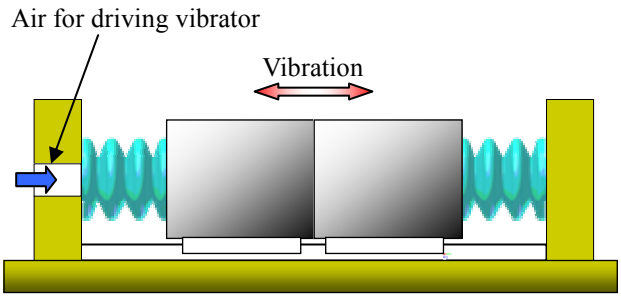
Fig. 4 Results of simulation (left; frequency of force is resonance frequency, right; frequency of force is non-resonance frequency)

4. Vibrating Experiments

An experiment model for confirming basic principle is configured from results of the simulation as in Fig. 5. This experiment model is constructed by two vibrators, rubber bellows and linear guide for controlling the axial movement. The vibrators are supported by a fine linear gudes to decrease the influence of friction. In this experiment, there are two models to confirm the working principle of multiplex pneumatic transmission. The first model uses stainless vibrator while the latter uses aluminum vibrator. They have different amount of mass resulting in different resonant frequency. In this experiment model, the pneumatic pressure is applied to the vibrator through the rubber bellows. The rubber bellows which are made from silicone rubber work as spring and pneumatic supply channel. This rubber bellows have an optimized spring constant which was realized through structural analysis using FEM. From the analyzed data, the mold was designed and fabricated by mold casting using CAD/CAM software. This process is shown in Fig. 6 below and the parameters of this experiment model are shown in Table 1. The error of resonance frequency found in Table1 comes mainly from the spring constant error.



(a) External view (one set of vibrators are removed showing inside)

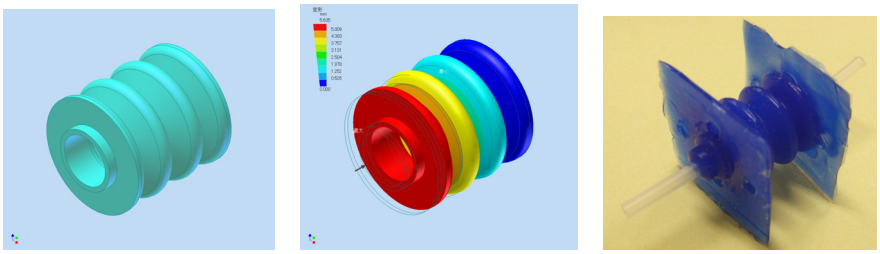


(b) Cross- section drawing

Fig. 5 Experiment model

Table 1 Parameters of the experiment model

	Vibrator		Bellows	Resonance frequency	
	Material	Mass	Spring constant	Theoretical value	Real value
Symbol		m	k	f_n	
Model 1	stainless	226 [g]	0.175 [N/mm]	4.4 [Hz]	7.6 [Hz]
Model 2	aluminum	76 [g]		7.6 [Hz]	10.5 [Hz]



(a) Designing (b) Analysis (c) Molding

Fig. 6 Designing of rubber bellows

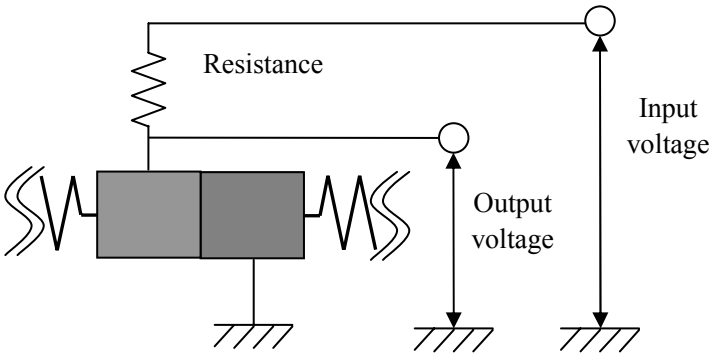
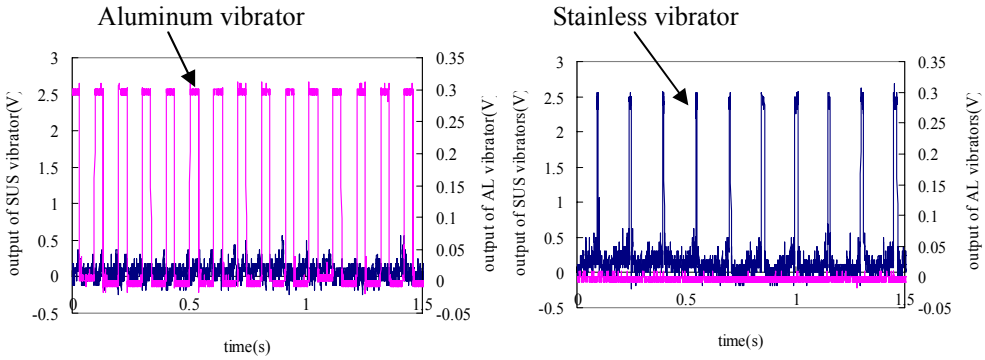
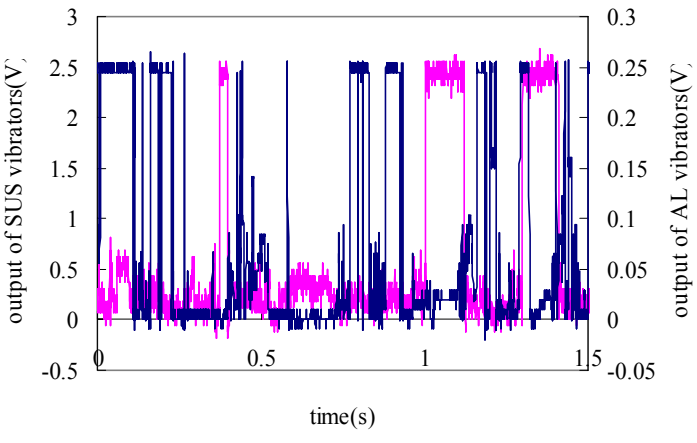


Fig. 7 Conduction Experiment



(a) Resonance frequency of each model (left; aluminum right; stainless)



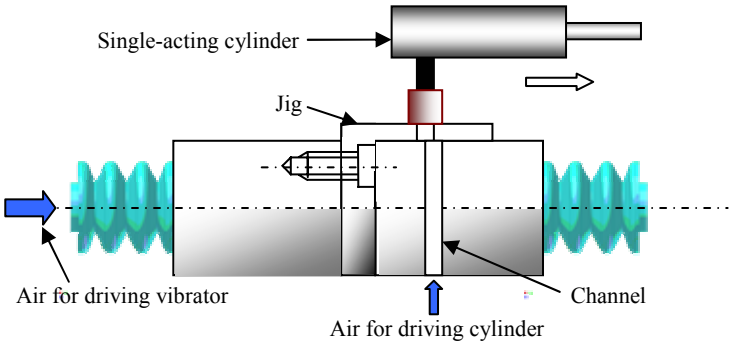
(b) Response of multiplex pneumatic transmission

Fig. 8 Results of conduction experiment

This experiment model is only applied to confirm the basic principle by resonance phenomenon thus it does not have function of pneumatic valve. Contact/non-contact states between the vibrators are detected by electric continuity working between them. Figure 7 shows the electrical circuit for this experiment. The output voltage is 0 [V] when the vibrators contact each other during driving at non-resonance frequencies. It becomes high voltage during driving at resonant frequency and separating each others. From Table 1, the materials of models 1 and 2 have different mass value making the resonance frequency different. Figure 8 shows the experiment results of motions of two vibrators; Fig.8 (a) shows the responses of the vibrators by applying single pneumatic vibrations of the resonant frequency of each vibrators. Fig.8 (b) shows responses for applying superimposed vibration of two resonant frequencies. The working principle of multiplex pneumatic transmission is confirmed through these results.

5. Pneumatic Experiments

Pneumatic experiments using this model were made as a basic example of pneumatic valve in Fig. 9. The valve is for an exhausting pneumatic valve for single-acting cylinder. As shown in the figure, each vibrator has its own functions; one for control resonance phenomenon and the other is for driving single-acting cylinder. A channel for the driving single-acting cylinder is situated at the right vibrator as shown in Fig. 9. Pressure can be applied to the single-acting cylinder when the vibrating frequency in the air is the non-resonance frequency. When these vibrators are driven at resonance frequency, the vibrators cut off the channel to the cylinder and air pressure. The rod of single-acting cylinder will be controlled following the resonance frequency value. Figure 10 shows the pressure fluctuation of single-acting cylinder.



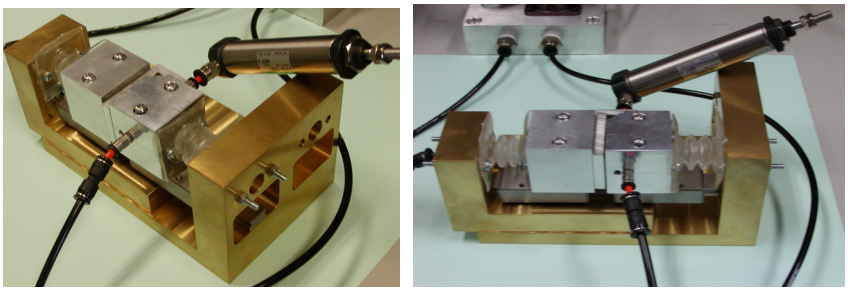


Fig.9 Application using experiment model; emission valve for pneumatic cylinder

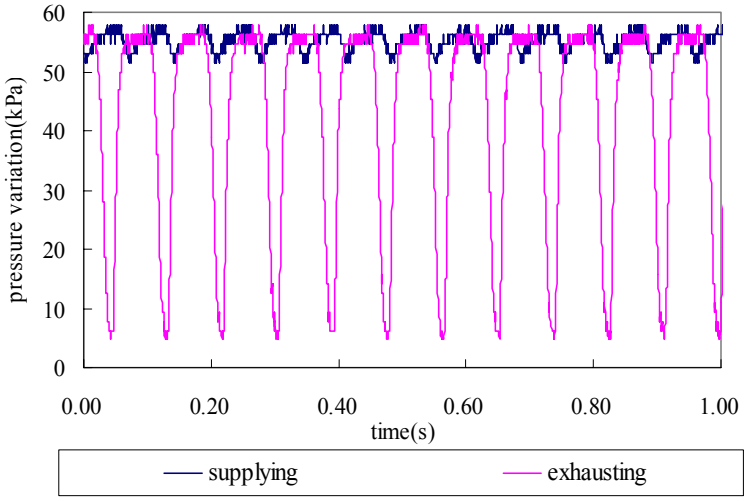


Fig.10 Pressure fluctuation of the exhausting valve

Supplying pressure from compressor to the valve is 300 [kPa]. The pressure in the single-acting cylinder in non-resonant mode is about 55 [kPa]. Servo valve is used to applyng pneumatic vibrations to the supply line, which works up to 50 [Hz]. This pressure drop comes from leak between jig and vibrator. The minimum pressure in resonant mode is about 5 [kPa]. The position of the piston rod was controlled successfully by this system showing the potential of this new driving principle.

6. Conclusion

A new principle for pneumatic valve is proposed. This new principle makes pneumatic valve possible to be driven without electric wire. The proposed valve which is simple and cheap is only configured with two vibrators and springs. A servo system is constructed where multiplex pneumatic transmission from the servo system can control several proposed valves independently. This valve was developed for pneumatic mechatronics system configuring many actuators and having many degrees of freedom.

The basic working principle is confirmed by dynamic simulations and real time experiments. Simple model was used in the simulation while the experiment model is similar to proposed principle model. The experiment model consists of vibrators, rubber bellows and liner guide. The rubber bellows have functions as spring and also as flow channel while the liner guide is for keeping the axial position. Spring constant of rubber bellows is decided by structural analysis using FEM. In the experiment, the model does not work as pneumatic valve however it is to confirm the working principle of proposed valve.

Authors adapted this experiment model to application of exhausting pneumatic valve. This application can be applied simply using experiment model. It has two control modes, suction and emission with different amount of pressure. From the results, the piston rod is found to be controlled and potential as pneumatic valve was shown.

Acknowledgment

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